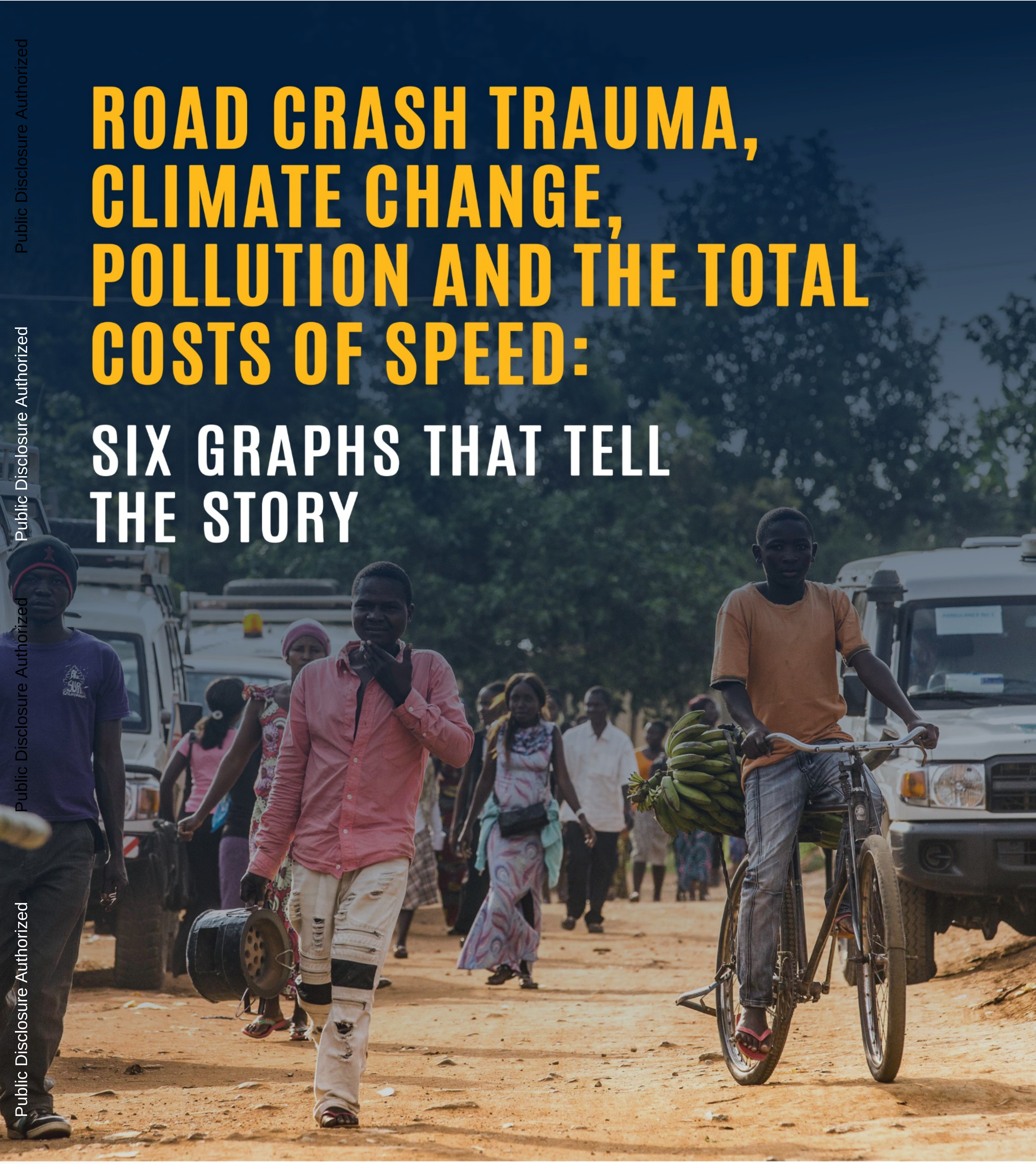
ROAD CRASH TRAUMA, CLIMATE CHANGE, POLLUTION AND THE TOTAL COSTS OF SPEED:

SIX GRAPHS THAT TELL THE STORY



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1818 H Street NW
Washington DC 20433
Telephone: 202-473-1000
Internet: bit.ly/GlobalRoadSafetyFacility

This report was written by Soames Job (Head of the GRSF and Global Road Safety Lead, World Bank) and Leah Watetu Mbugua (Junior Professional Officer, GRSF, World Bank). The preparation of this report was supported by Bloomberg Philanthropies and UK Aid, as donors to GRSF. This note was greatly improved by review comments from Alina Burlacu, Blair Turner, Juan Miquel Velasquez, Radoslaw Czapski, and Sudeshna Mitra.

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SPEED, ROAD SAFETY, CLIMATE, AND TOTAL COSTS OF TRAVEL:

SIX GRAPHS THAT TELL THE STORY

The impacts of speed on the safety of road users, on congestion, on pollution, and on total costs of road travel are broadly misunderstood: often based on wrong assumptions, with effects taken as self-evident, failure to consider multiple impacts, externalization of costs by many stakeholders, and under-estimation of impacts (especially economic costs of higher speeds). The purpose of this brief note is to provide information on these relationships relevant to fundamental road transport policies, design, and operation. Well-established evidence shows the importance of managing travel speeds for road safety, for efficiency, for improved inclusion, and for greenhouse gas (GHG) and other emissions. Thus, speed management is a strong policy lever for the breadth of issues which must be addressed for sustainable mobility.[1]

Reduced speeds of travel represent a major, yet under-appreciated, opportunity to improve safety, climate change impacts of travel, health, inclusion, the economy, and in some circumstances, congestion. Speed management can be achieved through a range of interventions including road infrastructure and vehicle technology, as well as enforcement and promotion.

Just six graphs below tell a powerful story, across the range of these benefits of speed management.

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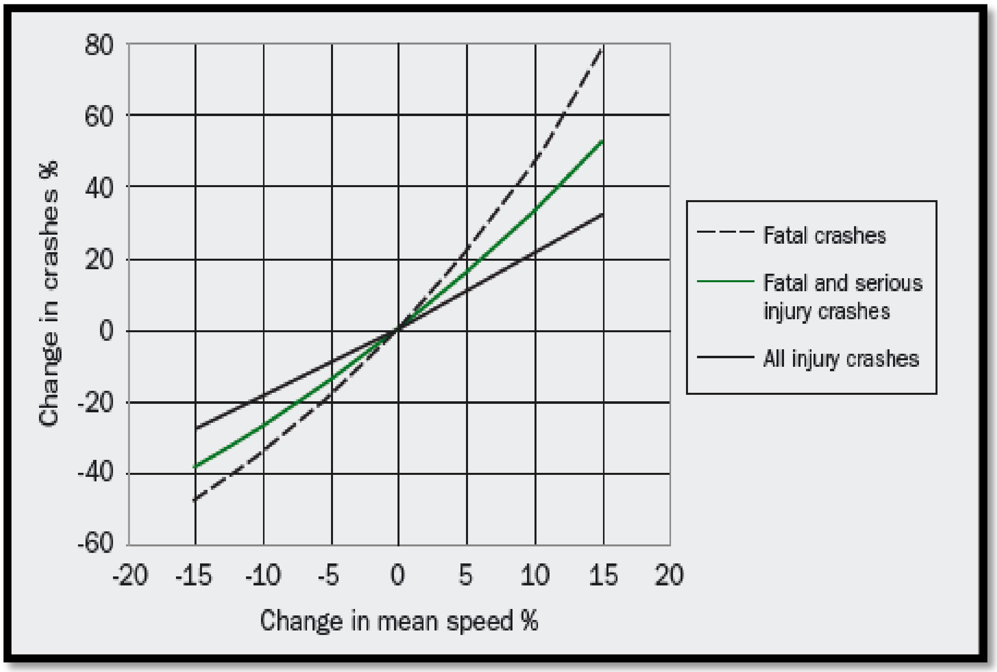
[1] Sustainable Mobility for All (2017). *Global Mobility Report 2017*. Sustainable Mobility for All: Washington, DC.

GRAPH 1:

Small changes in speed have large impacts on road crash deaths and injuries: Each 1% increase in speed results in a 3.5% to 4% increase in deaths



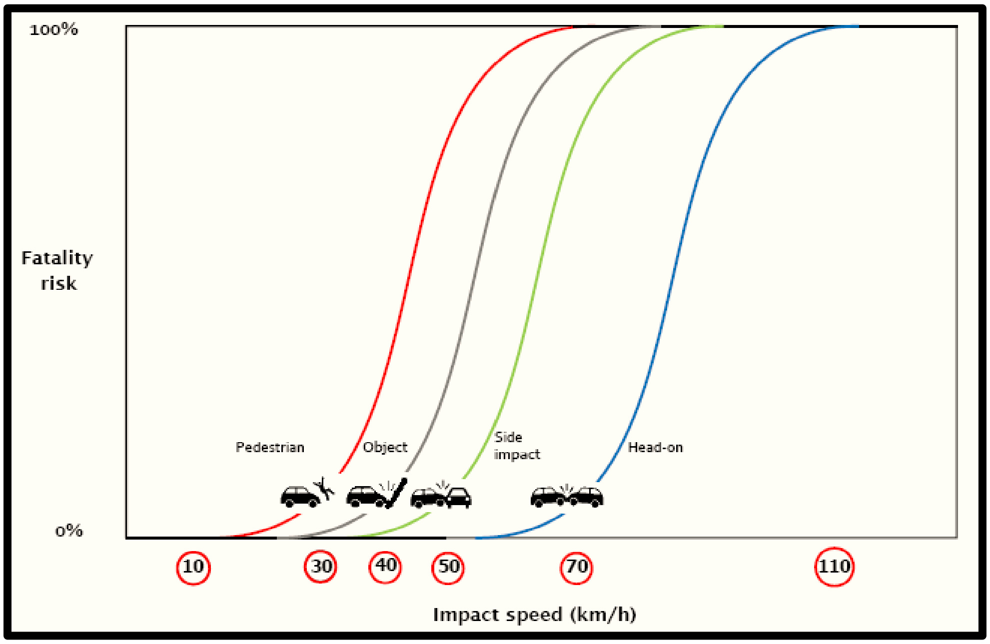
(Source: Nilsson, 2004)[2]

Graph 1 shows the relationship between changes in speed and fatal, serious injury and all injury crashes, based on an extensive synthesis of many international studies.[3] Subsequent re-analyses and follow-up research evaluations validate these fundamental influences of speed on safety.[4 5 6 7] Changes in speed has even greater impacts on higher severity crash outcomes with very small changes in speed having dramatic impacts on fatal outcomes.

The role and impact of speed in serious crashes is often underestimated. Most of us know that speed is a major determiner of crash severity, but many assume that speed does not influence crash occurrence. Higher speeds increase crash probability through several mechanisms: by reducing the capacity to stop in time; by reducing manoeuvrability in evading a problem; by making it impossible to negotiate curves and corners at speeds which are too high for the friction available; by reducing the driver's field of vision; and by causing others to misjudge gaps. For example, a vehicle travelling above the speed limit allows pedestrians less gap to cross the road than expected for the distance between the pedestrian and the vehicle.[8]

[2] Nilsson, G. (2004). *Traffic Safety Dimension and the Power Model to describe the Effect of Speed on Safety*. Lund Institute of Technology, Sweden.
[3] Nilsson, G. (2004). *Traffic Safety Dimension and the Power Model to describe the Effect of Speed on Safety*. Lund Institute of Technology, Sweden.
[4] Elvik, R., Høye, A., Vaa, T., & Sørensen, M. (2009). *The handbook of road safety measures*. Bingley. UK: Emerald Group Publishing Limited.
[5] Elvik, R. (2010). A restatement of the case for speed limits. *Transport Policy, 17(3),* 196-204.
[6] Elvik, R 2013, 'A re-parameterisation of the power model of the relationship between the speed of traffic and the number of accidents and accident victims', *Accident Analysis & Prevention*, vol. 50, pp. 854–60.
[7] Elvik, R, Vadeby, A, Hels, T & van Shagen, I, 2019, Updated estimates of the relationship between speed and road safety at the aggregate and individual levels, *Accident Analysis & Prevention*, vol. 123, pp. 114-122
[8] Job, RFS & Sakashita, S. (2016). Management of speed: The low-cost, rapidly implementable effective road safety action to deliver the 2020 road safety targets. *Journal of the Australasian College of Road Safety, May 2016*, 65-70.

GRAPH 2:
Risk of death by speed of impact changes for different crash types



(Source: GRSP, 2005)[9]

Graph 2 shows the risk of deaths for each speed for different crash types: pedestrian crashes, crashes into rigid objects, side impact crashes, and head-on crashes. The influence of speed on risk of death is dramatic, and leads to the safe system speed limits.[10] The safe system approach to road safety acknowledges that humans will always make mistakes and thus road safety cannot be achieved by relying on fixing the road users to behave safely all the time. The human body is also vulnerable to force, and thus a safe system is one in which despite errors which result in crashes humans are not exposed to forces which result in deaths or debilitating injury. Speeds are vital to achieving this. For a system to be considered safe one of two situations are required:

1. The crash type must be physically banned (for example by grade separation of intersections or implementation of well-designed roundabouts in the case of side-impact crashes, or median barriers in the case of head-on crashes), or
2. If the crash type is possible, then speeds must be managed down to safe levels for that crash type. Safe speeds are, by convention, set at a point which will allow a 90% survival rate, as below:
   - 30km/h for impacts with pedestrians (and other vulnerable road users such as bicyclists);
   - 40km/h for impacts with solid objects;
   - 50km/h for car to car side impact crashes; and

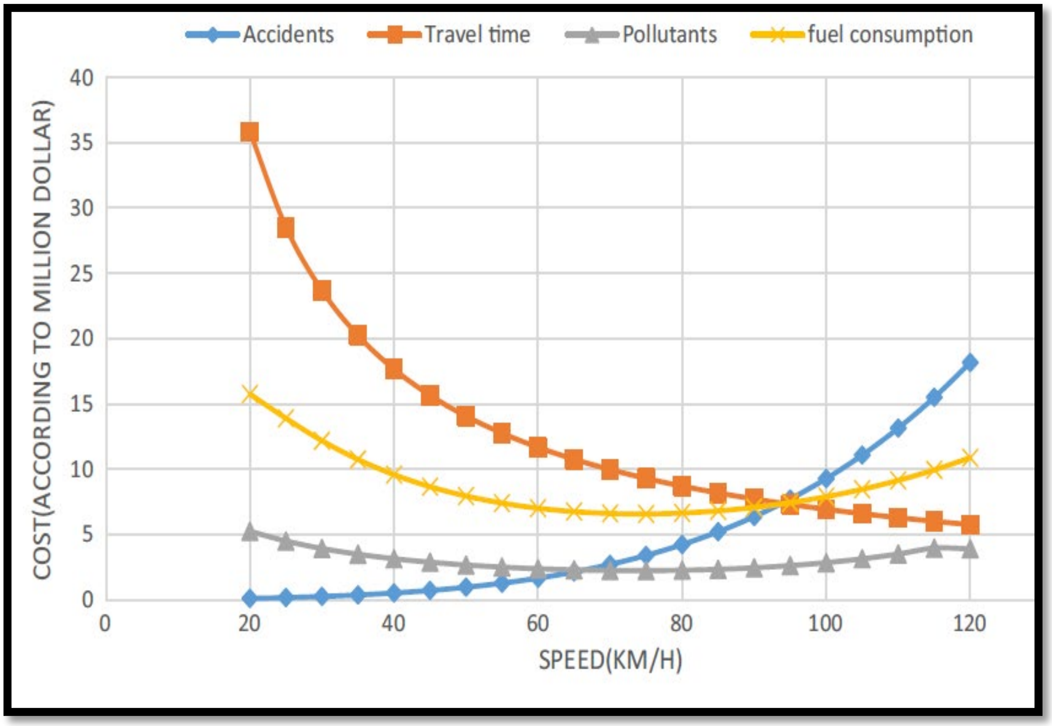
9 Based on one conference presentation by Wramborg (2005)
[10] GRSP (Global Road Safety Partnership) (2008). *Speed management: a road safety manual for decision-makers and practitioners*. Geneva, Global Road Safety Partnership. Available at: http://whqlibdoc.who.int/publications/2008/9782940395040_eng.pdf

- 70km/h for head-on crashes.

These speeds apply to fatal crash outcomes. When avoiding serious injury, the speeds need to be lower than those identified above. More recent analyses of the speed and risk indicate that the speed at which 10% of pedestrian are killed may be slightly higher than above[11] but also the need for lower speeds- especially for pedestrians, for whom 10% will be seriously injured at an impact speed of only 20 kmh.[12]

GRAPH 3:

Increases in speed have large impacts on multiple components of travel cost



(Source: Hosseinlou et al., 2015)[13]

Graph 3 shows the economic costs of travel at various speeds on a divided carriageway (motorway) not highway or rural roads, in Iran. Hosseinlou et al. (2015) found that the economically ideal speed for the motorway for the society was 73km/h, well below the speed limits applied globally to motorways, which are often 100kmh to 130kmh.

Economic analyses of higher speeds often only consider travel time savings, omitting critical economic impacts through crash costs, emissions, fuel costs and vehicle maintenance. The total costs of speed are often overlooked because lobbying by transport companies and other road

[11] Hussain, Q., Feng, H., Grzebieta, R., Brijs, T., & Olivier, J. (2019). The relationship between impact speed and the probability of pedestrian fatality during a vehicle-pedestrian crash: A systematic review and meta-analysis. *Accident Analysis & Prevention*, *129*, 241-249

[12] Jurewicz, C. Sobhani A, Woolley J, Dutschke J, Corben B. 2016. "Exploration of vehicle impact speed–injury severity relationships for application in safer road design." Transportation research procedia 14: 4247-4256.

[13] Hosseinlou, MD., Kheyrabadi, SA., Zolfaghari, A. (2015). Determining optimal speed limits in traffic networks. *International Association of Traffic and Safety Sciences*, 39(1):36-41.

users is focused on their travel time, while the main costs of crashes, GHGs, and health effects of omissions are born by the society and government.

MANAGING SPEEDS:

- Saves lives and debilitating injuries
- Reduces GHG emissions and thus assists in the battle against climate change (in recent meeting in Geneva, Sweden reported that the most effective tool they had for reducing GHGs was the speed camera program)
- Reduces other air pollutants which harm health[14], including road traffic noise[15]
- Increases efficiency, by vehicle maintenance costs and reducing fuel costs[16]
- Increases access for all by reducing the risk of pedestrians who must risk crossing high speed roads in their commutes or journeys to school and other vulnerable road users mixing with high speed traffic.

Studies of the full economic impacts of speed are rare, in itself reflecting neglect of the breadth of impacts of travel speed and leading to the current domination of travel time in analyses which then (mis)guide vital transport policy decisions. However, several studies exist, and show that in High Income Countries (HICs) economically optimal travel speeds are lower than expected and typically lower than the posted speed limits. For example, on 100km/h speed limited sealed rural roads with 3.5m lanes in Australia the economically ideal speed was around 85km/h for truck and between 85 and 90km/h for cars depending on the extent of curves.[17] In Norway, the economically ideal speed was 76km/h, though this calculation generates a higher speed because it only considered travel time savings and crash costs. If the other costs noted above were considered (GHGs, emissions, fuel, etc.) the economically optimal speed would be significantly lower. Importantly, one study exists for a Middle-Income Country (MIC), of the Shiraz- Marvdasht motorway in Iran (as presented in Graph 3).

Graphs and research on economically ideal speeds are only available for non-urban roads. However, with stop-start traffic, more vulnerable road users creating greater risks of serious injuries and costs, and higher impacts on health of emissions, economically optimal speeds in urban environments are much lower.

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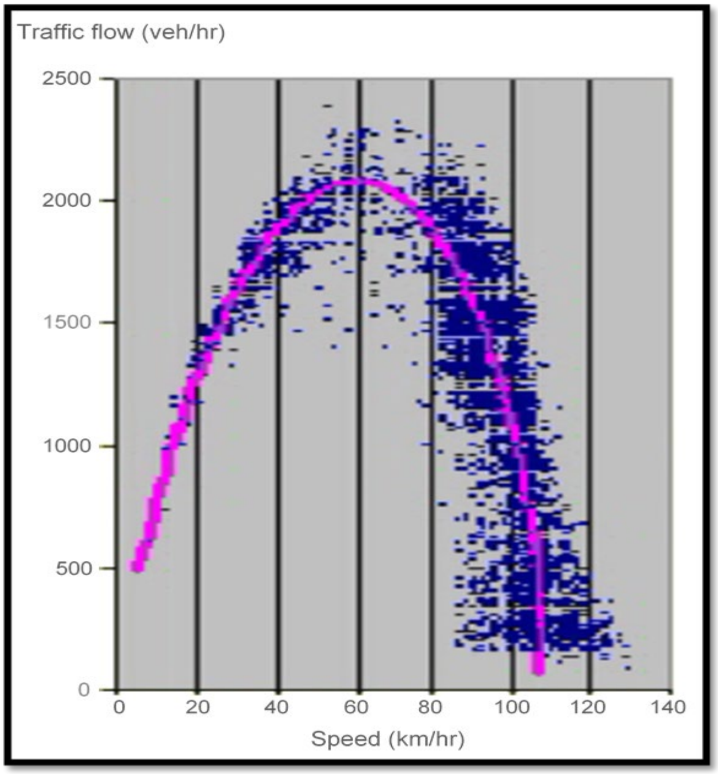
[14] WHO (2013). *Review of evidence on health aspects of air pollution – REVIHAAP project: final technical report*. Geneva: World Health Organization (WHO).
[15] Job, RFS (1996). The influence of subjective reactions to noise on health effects of the noise. *Environment International*, 22:93-104.
[16] Thomas, J., Hwang, H., West, B., and Huff, S. (2013). Predicting Light-Duty Vehicle Fuel Economy as a Function of Highway Speed, *SAE International Journal of Passenger Cars - Mechanical Systems* 6(2):859-875, doi:10.4271/2013-01-1113.
[17] Cameron, M. (2003). *Potential benefits and costs of speed changes on rural roads.* Report CR216. Monash University Accident Research Centre, Victoria Australia.
Cameron, M. (2012). Optimum speeds on rural roads based on 'willingness to pay' values of road trauma. *Journal of the Australasian College of Road Safety,* 23(3):67-74.

GRAPH 4:

The relationship between speed and traffic flow: Showing that decreasing speeds does not necessarily increase congestion, and can improve congestion



(Source: OECD, 2006)[18]

Graph 4 shows the theoretical curve relating speed to traffic flow (in pink), along with the actual data from many locations showing an excellent fit with the curve (in blue dots). At low levels, as speeds increase the traffic flow initially improves but with further increases in speed, the reverse effect occurs: traffic flow through a specific location is reduced as speeds increase. Thus, increasing speeds to this level will in net increase congestion. This arises in significant part because as speeds increase drivers should (and generally do) leave longer gaps between themselves and the vehicle in front. Thus, at high speed, vehicles are further apart. Thus existing congestion will not be improved by increasing speed limits beyond around 50km/h. Based on this knowledge, variable speed limits (including managed freeways) have been used in many countries with positive results for both improved safety and reduced congestion.[19] Reductions in speed limits as vehicles reach congested conditions results in a smoother flow of traffic. This produces less stop/start traffic movement, with subsequent benefits on safety and throughput of vehicles.

Congestion is a significant issue in many major developed and LMIC cities. A common assumption among policy makers and politicians is that increasing speed limits (and thus speeds) will solve congestion. This assumption is largely false, as shown in Graph 4. There are additional

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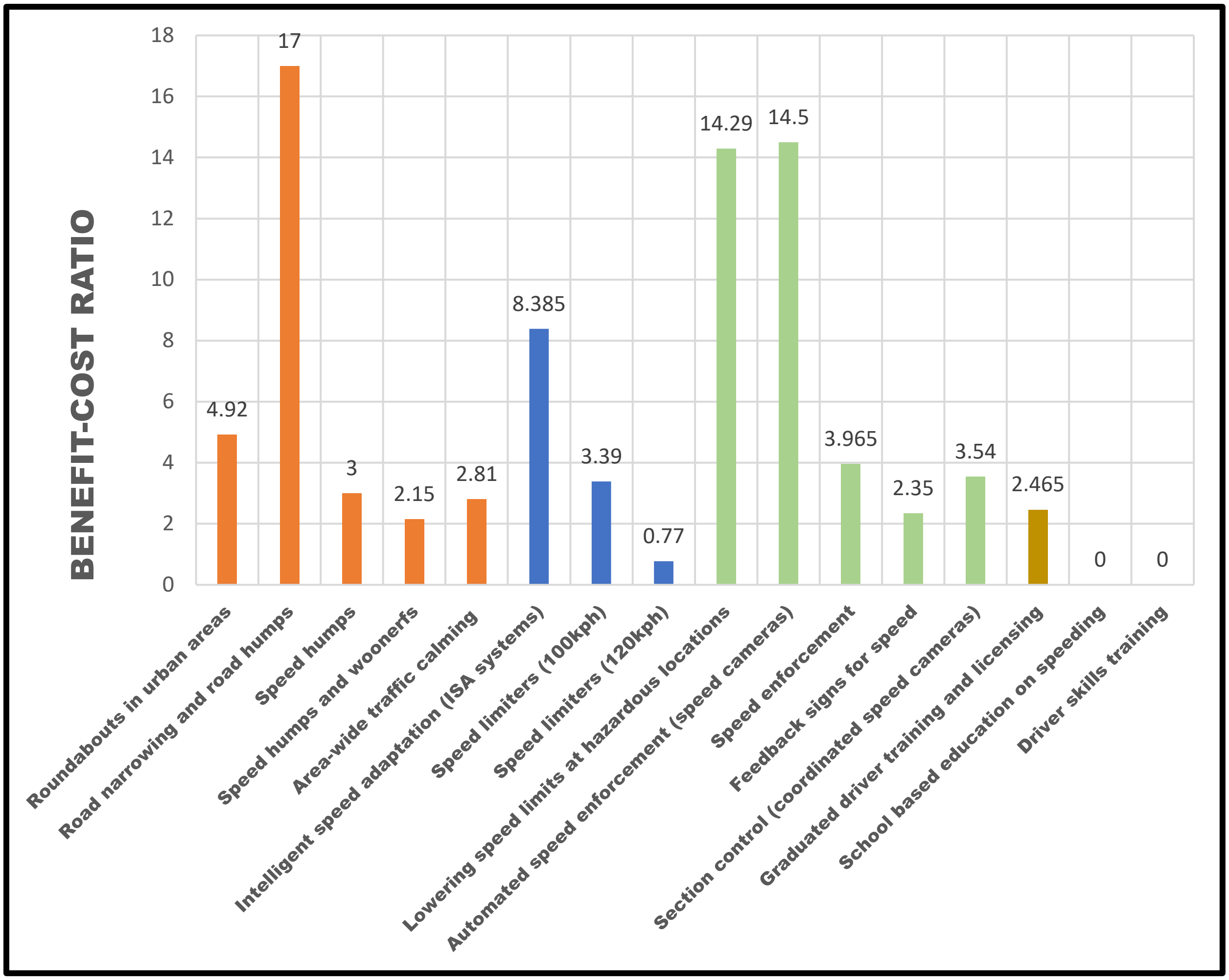
[18] OECD. (2006). *Speed Management.* Report of the Transport Research Centre, ECMT Paris.
[19] Han, C, Luk, J, Pyta, V & Cairney, P, 2009, Best Practice for Variable Speed Limits: Literature Review, AP–R342/09, Austroads, Sydney, Australia.

factors. First, by definition, congestion means that the traffic is not able to reach the speed limit, and thus higher speed limits will not solve the problem of excessive traffic for the road space available. Second, for trips within urban areas, the primary generators of congestion are intersections, traffic queues and unilateral braking for cornering and turns[20].

While turning speeds are unaltered by speed limits, intersection efficiency and traffic queueing are beneficially affected by lower speeds owing to reduced spacing, improved merging of traffic flows and decreased collisions. Thus, it is not surprising that studies have reported that lower speed limits can reduce travel times in urban areas.

GRAPH 5:

Benefit-Cost Ratios for various Road Engineering, Vehicle Engineering, and Behavior Change Interventions for Speed Management



(Developed from multiple sources: See Annex 1)

[20] Archer, J., Fotheringham, N., Symmons, M., & Corben, B. (2008). The impact of lowered speed limits in urban and metropolitan areas (Report# 276). *Monash University Accident Research Centre (www. monash. edu. au/miri/research/reports/muarc276. pdf).*

Graph 5 shows benefit cost ratios for a number of speed management interventions, demonstrating that powerful and cost-effective interventions exist beyond enforcement. For LMICs with deep challenges in the systems required to deliver effective enforcement, simple road engineering measures such as lane-narrowing and speed humps may be the most effective, sustained intervention for urban and low or moderate speed environments.

The default singular focus on enforcement (and education) to manage speed is misguided and unhelpful. Unfortunately, many road safety strategies and plans invite this error by including speed management under the safe road users (or behavior change) pillar. More effective speed management arises in strategies which include safe speed as a separate pillar of road safety action, facilitating a broad approach to the issue.[21]

Speed may be managed through effective road design and engineering and vehicle interventions, as well as the more traditional approaches to behavior change. Proven road interventions include speed humps, well-designed roundabouts, raised platform crossings, chicanes, road lane narrowing though reducing the travel lane and increasing the shoulder in line marking, gateway treatments, and setting appropriate speed limits. All are proven to be effective and are typically more sustainable than reliance on enforcement.[22]

Vehicle policies also allow for effective speed management. Many countries including those in the European Union require heavy vehicles to be speed limited (or in some cases continuously speed monitored). The European Parliament has mandated Intelligent Speed Adaptation (ISA) for all new vehicles with a lead up period of just a few years. ISA technology has proven road safety benefits, as well as beneficial effects on fuel consumption and emissions.[23] [24] [25]

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[21] Examples of strategies which include the dedicated speed pillar include Ireland, Australia, and Qatar:
Australian Transport Council (2011). *National Road Safety Strategy 2011–2020*. Canberra: ACT.
Road safety Authority [Ireland] (2013). *Road Safety Strategy 2013—2020*.
National Traffic Safety Committee [Qatar] (2012). *2012-2021 Qatar National Road Safety Strategy: Safe Road Users, Safe Vehicles Safe Roads, Safe Speeds*. Doha: National Traffic Safety Committee.

[22] Huang, J., Liu, P., Zhang, X., Wan, J., and Li, Z. (2011). Evaluating the Speed Reduction Effectiveness of Speed Bump on Local Streets. ICCTP 2011: pp. 2348-2357. http://ascelibrary.org/doi/abs/10.1061/41186(421)234
Makwasha, T. and Turner, B. (2013). Evaluating the use of rural-urban gateway treatments in New Zealand. *Journal of the Australasian College of Road Safety*, 24(4):14-20.
For reviews see:
WHO (2013). *Pedestrian Safety: A road safety manual for decision-makers and practitioners*. Geneva: World Health Organization (WHO).
GRSP (2008). *Speed Management: A road Safety Manual for decision makers and practitioners*. World Health Organisation/Global Road Safety Partnership (WHO/GRSP), 2008.

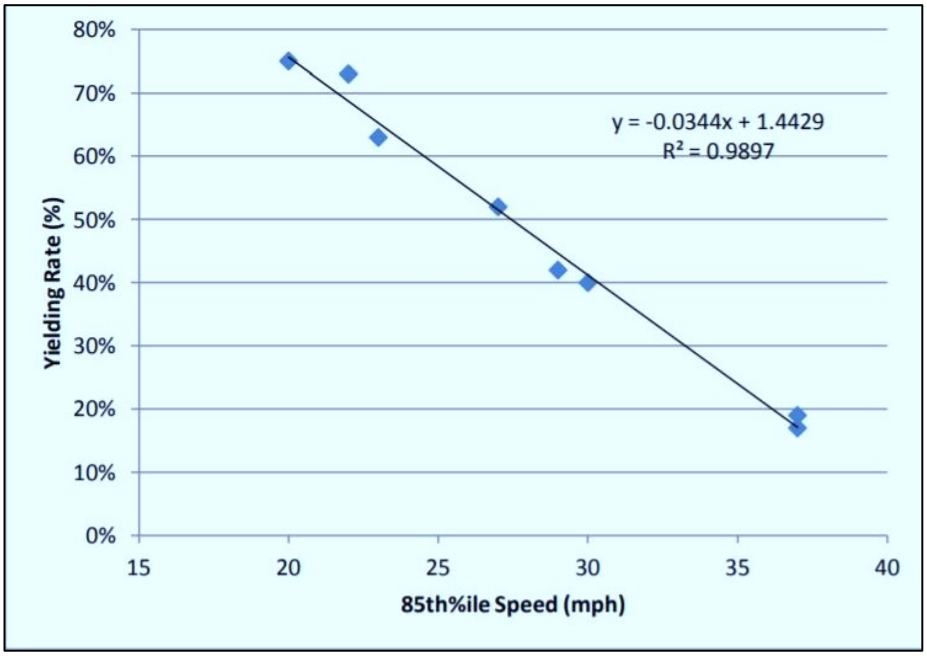
[23] Carsten, OMJ., Fowkes, M., Lai, F., Chorlton, K., Jamson, S., Tate, FN., Simpkin, R. (2008). *Intelligent speed adaptation: Final report to Department for Transport*. June 2008. University of Leeds and MIRA Ltd.

[24] Lai, F., Carsten, O. & Tate, F. (2012) How much benefit does intelligent speed adaptation deliver: an analysis of its potential contribution to safety and environment. *Accident Analysis and Prevention, 48*, 63-72.

[25] European Commission (2015) *Speed and Speed Management.* Brussels: E.C.

GRAPH 6:

The inverse relationship between the rate of drivers yielding to pedestrians and Approach traffic speed: Lower speeds create pedestrian-friendly environments and promote inclusion



(Source: Bertulis and Dulaski, 2014[26])

Graph 6 shows the effect of motor vehicle speeds (measured as the 85th percentile speed which is determined by the characteristics of the built environment as well as posted speed limits) on yielding to pedestrians in marked crosswalks. As driver speeds increase, the percentage of drivers who yield to pedestrians at marked crosswalks decreases dramatically, highlighting that lower speeds promote safety, inclusion, and equity amongst road users.

Certain speed-reducing engineering treatments also have spatial benefits that further promote inclusion. One such treatment is a road diet, which is generally described as reducing the number of travel lanes and/or narrowing travel lanes in a roadway to utilize the space for other uses and travel modes. This is one strong option for consideration in building BRTs. By narrowing marked lanes, lower speeds can be achieved[27,28,29] which creates a more comfortable environment for all road users including pedestrians and cyclists.

Thus, **the benefits of implementing a road diet on urban streets include:**

- Reclaimed space to serve other modes including bike lanes and sidewalks which improves mobility and access for all road users.

[26] Bertulis, T., & Dulaski, D. M. (2014). Driver approach speed and its impact on driver yielding to pedestrian behavior at unsignalized crosswalks. *Transportation Research Record, 2464(1),* 46-51.
[27] Fitzpatrick, K., Carlson, P., Brewer, M., & Wooldridge, M. (2001). Design factors that affect driver speed on suburban streets. *Transportation Research Record, 1751(1),* 18-25.
28 Poch, M., & Mannering, F. (1996). Negative binomial analysis of intersection-accident frequencies. *Journal of transportation engineering, 122(2),* 105-113.
29 Farouki O., Nixion W., (1976). The Effect of the Width of Suburban Roads on the Mean Free Speed of Cars. *Traffic Engineering and Control,* December, pp. 518-519.

- Lower speeds which accommodate all (especially vulnerable) road users.
- Reclaimed space for geometric features that enhance safety such as medians, pedestrian refuge islands and turn lanes.
- Shorter pedestrian crossing times because of reduced crossing distances.
- Reduced interference with surrounding development.
- The designs are more economical to construct compared to conventional ‘upgrades’ which further widen urban roads.
- Less stormwater runoff as more space can be left as vegetation.

TAKE AWAY MESSAGES

1. Common sense approaches to speed policy are misleading and inconsistent with the (sometimes counterintuitive) practical scientific evidence.

2. Reducing speed is one of the most effective ways to improve safety, saving lives and debilitating injuries.

3. Reducing speeds also generates multiple other benefits fundamental to sustainable mobility: reduced climate change impacts of road transport, increased efficiency (fuel and vehicle maintenance), improved inclusion and walkability.

4. Analyses of the full range of economic impacts of various speeds show quite different ideal speeds from those generated by consideration of travel time savings alone. Economically optimal speeds are lower than expected and typically lower than prevailing speed limits.

5. Common reasons for not lowering speeds (concerns with congestion, economic growth, and reliance on enforcement) are shown to be inaccurate.

6. Mass transit and reducing demand for mobility (through improved urban design and development policies) offer opportunities to manage congestion.

7. Vehicle policies, road design and engineering allow for strong, more sustainable, often more politically viable management of speed than reliance on enforcement alone.

8. Improving driver skills is not a viable alternative to managing speeds, with studies showing that skills-based training does not improve safety and may do harm.

WHAT WORKS WELL AND WHAT DOES NOT FROM THIS NOTE

WHAT WORKS WELL

- Managing speeds down as a vital proven intervention for sustainable transport - saving lives, injuries, economic costs of crashes, and co-benefits in climate change, noise, pollution, efficiency, and inclusion.
- Employing a range of techniques for reducing speeds, especially including road infrastructure features, and improved communication with all types of road users on the topic.
- Considering mass transit as a solution to congestion and safety, not increasing speeds (which do not work as expected)
- Considering all elements of cost in determining speeds, not just travel time.
- Employing a rigorous evidence-based approach to selection of road safety interventions, and consider providing the evidence herein to decision makers to guide their choices.
- Including speed management as a distinct pillar of road safety interventions in road safety strategies and plans, to reflect is vital importance and avoid interventions being confined to improving road users.
- Adopting supervised on-road driver training as the only form of driver training proven to have safety benefits for novice drivers (See Annex 2).

WHAT DOES NOT WORK WELL

- Accepting or not resisting the (wrong) assumption that increasing speeds will reduce congestion or that reducing speeds will increase congestion.
- Accepting or not resisting the (wrong) assumption that increasing speed generally leads to improved economic outcomes.
- Simply adding a reduced speed limit on a road section, without changing the geometric features of the road.
- Treating enforcement as the first option for reducing speed.
- Employing driver training or education as alternatives to improved speed management.

ANNEX 1 | BENEFIT: COST RATIO (BCR) ESTIMATES FOR SPEED MANAGEMENT MEASURES

THE DATA

	MEASURE	BCR	SOURCE	COUNTRY/ REGION	NOTES
ROAD ENGINEERING MEASURES	Roundabouts	1.86	SafetyNet (2009); Elvik (2007)	Norway	Converting T-junctions to roundabouts in urban areas
	Roundabouts	2.62	SafetyNet (2009); Elvik (2007)	Norway	Converting X-junction to roundabouts in urban areas
	Roundabouts	1.23	Promising (2001); Höhnscheid, et al (2006)	Norway	Converting T-junction to roundabouts in urban areas
	Roundabouts	8.61	Promising (2001); Höhnscheid, et al (2006)	Norway	Converting X-junction to roundabouts in urban areas
	Roundabouts	1.52 - 2.26	Elvik (1999); Elvik (2001); Elvik & Amundsen (2000)	Norway & Sweden	In urban areas
	Roundabouts	1.5	Winkelbauer (2005); Höhnscheid, et al (2006)	Czech Republic	In urban areas
	Roundabouts	2.95	Yannis, Evgenikos & Papadimitriou (2008)	Ireland	
	Roundabouts	7.5	Torpey, Ogden, Cameron & Vulcan (1991)	Victoria	Treating 200 X-intersection sites
	Road narrowing and road humps	17	Höhnscheid, et al (2006); SafetyNet (2009)	Germany	In residential areas
	Speed humps	2:1 -4:1	Winkelbauer (2005); SafetyNet (2009); Yannis, Evgenikos & Papadimitriou (2008)	Israel	On urban streets
	Speed humps and woonerfs	1.9 - 2.4	Yannis, Evgenikos & Papadimitriou (2008)	Greece	On urban roads and area-wide. BCR=1.9 when lost time is included, BCR=2.4 safety benefits only

	Area-wide traffic calming	1.94 - 3.68	Yannis, Evgenikos & Papadimitriou (2008)	Ireland	Combination of measures including junction improvements, traffic calming, safety barrier, road markings, surfacing, warning signage and improving sight distance
VEHICLE ENGINEERING MEASURES	Intelligent speed adaptation (ISA systems)	1.95	SafetyNet (2009); Elvik (2007)	Norway	
	Intelligent speed adaptation (ISA systems)	1.37	Elvik (2001); Elvik & Amundsen (2000)	Sweden	
	Intelligent speed adaptation (ISA systems)	7.9-15.4	Carsten & Tate (2005).	UK	From implementation of a mandatory system of fitting all vehicles with speed limiters
	Speed limiters (100kph)	2.47 - 4.31	Albert, Toledo & Hakkert (2007)	UK and Germany	For European light goods vehicles
	Speed limiters (120kph)	0.56 - 0.98	Albert, Toledo & Hakkert (2007)	UK and Germany	For European light goods vehicles
ENFORCEMENT MEASURES	Lowering speed limit on hazardous locations	14.29	SafetyNet (2009); Elvik (2007)	Norway	
	Automated speed enforcement (speed cameras)	5.3	ICF Consulting and Imperial College Centre for Transport Studies. (2003).	European Union	Installing the same number of speed cameras per km of road as in Great Britain (which had the highest density of speed cameras at the time) in all Member States
	Automated speed enforcement (speed cameras)	2.11	SafetyNet (2009); Elvik (2007)	Norway	Extending the use of speed cameras according to a plan prepared by Public Roads Administration
	Automated speed enforcement (speed cameras)	3	Goldenbeld and van Schagen (2005).	Netherlands	5-year enforcement program with mobile (hidden) cameras on rural roads in Dutch province Friesland
	Automated speed enforcement (speed cameras)	2.98	Höhnscheid, et al (2006)	Sweden	
	Automated speed enforcement (speed cameras)	2.03-8.88	Elvik (2001)	Norway	Current use of speed cameras in Norway

	Automated speed enforcement (speed cameras)	12	Torpey, Ogden, Cameron & Vulcan (1991)	Victoria	5-year enforcement program deterring speeds over 25kph
	Automated speed enforcement (speed cameras)	2.0 - 27.0	Elvik, Høye, Vaa & Sørensen (2009)	Europe	
	Speed enforcement	1.49	SafetyNet (2009); Elvik (2007)	Norway	
	Speed enforcement	2.89 - 3.62	Elvik (1999); Elvik (2001); Elvik (2003); Elvik & Amundsen (2000); Höhnscheid, et al (2006)	Norway & Sweden	
	Speed enforcement	0.87 - 7.06	Elvik (2001a)	Norway	Tripling the amount of speed enforcement carried out by police patrols
	Section control (coordinated speed cameras)	1.58	SafetyNet (2009); Elvik (2007)	Norway	
	Section control (coordinated speed cameras)	2.3	Elvik, Høye, Vaa & Sørensen (2009)	Norway	Converting existing system of cameras to section control
	Feedback signs for speed	2.35	SafetyNet (2009); Elvik (2007)	Norway	
	Section control (coordinated speed cameras)	5.5	Höhnscheid, et al (2006)	Vienna	Section Control – Automatic Speed Enforcement in the Kaisermühlen Tunnel (Vienna, A22, motorway)
EDUCATION AND TRAINING	Graduated driver training and licensing	1.43	Elvik (2001); Elvik & Amundsen (2000); Höhnscheid, et al (2006)	Sweden	Reforming basic driver training with one or several of the following elements: starting driver training at age 16 with licensing at age 18, minimum number of km of driving before driving test, special regulations for novice drivers, regarding systems for accident-free driving
	Graduated driver training and licensing	3.5	Höhnscheid, et al (2006)	Switzerland	Introduction of two-phase model of driver education
	Graduated driver training and licensing	1.82	TRL (2001); Höhnscheid, et al (2006)	Sweden	

	School based driver training	0	Roberts & Kwan (2001)	Multiple	This is repeatedly shown to deliver no safety benefit and, in some cases, to make road safety worse. The evidence suggests the contrary, mainly because young people start driving earlier. A comprehensive review of evaluations of school-based driver training produced negative results, concluding as follows: “The results show that driver education leads to early licensing. They provide no evidence that driver education reduces road crash involvement, and suggest that it may lead to a modest but potentially important increase in the proportion of teenagers involved in traffic crashes.”
	Post-license driver training for novice drivers	0	Ker et al. (2008). Ivers et al. (2016).	Multiple	Based on a systematic review of the evidence, Ker *et al.* concluded: “This systematic review provides no evidence that post-licence driver education is effective in preventing road traffic injuries or crashes. Because of the large number of participants included in the meta-analysis (close to 300,000 for some outcomes) we can exclude, with reasonable precision, the possibility of even modest benefits.” Similar failures to deliver road safety benefits have also been identified for motorcycle rider training.
	Driver trianing for novice drivers	Generally, adds no road safety value, but supervised on-road experience does improve safety for novice drivers	Gregersen, et al. (2003).	Multiple	Most forms of driver training for novices do not generate road safety value. However, effects vary with details of training. The only form of training proven to improve road safety for novice drivers is many hours of supervised on-road experience.

References for the data above are provided at the end of this note, while Annex 2 covers driver training.

ACHIEVING HIGHER BCRS IN LMICS

Evidence exists that certain speed management treatments would yield higher BCRs in low- and middle-income countries than those often reported in high income countries. Mohapatra (2017)[30] [31] reports that implementing area-wide traffic calming in Mombasa in Kenya and Addis Ababa in Ethiopia would yield BCRs of 17.56 and 36.51 respectively. UNECA and UNECE (2018)[32] also report BCRs of 30 for area-wide traffic calming in Kampala, Uganda. Similar treatments, on the other hand, have BCRs in the range of 1.9 - 3.68 for towns in Ireland and Greece[33]. The higher BCRs in LMICs reported for this treatment are a result of the application of low-cost effective measures (i.e. speed humps, tables, rumble strips) that negate issues of poor compliance (which often limits the effectiveness of treatments in LMICs), applied at locations that typically have higher crash numbers compared to HICs. Higher benefit-cost ratios for treatments implemented in LMICs may be achieved as a result of the following:

- Lower costs of implementation for certain treatments. While not all treatments may be expected to have lower costs, engineering treatments that utilize locally available materials and labor-intensive techniques on application can have lower costs.

- Greater benefits as treatments are implemented at locations that typically have higher crash numbers compared to HICs. Higher crash numbers in LMICs are indicative of the potential for greater life-savings[34]. To achieve these savings, effective techniques in the LMIC context would need to be applied. Some of the major challenges faced in LMICs including poor compliance, low maintenance operations, poor application of treatments and poor quality of materials often reduce the effectiveness of treatments. However, there are certain treatments whose mechanism is not as susceptible to these challenges. These treatment types may include those that reduce the severity (such as installing traffic calming devices to reduce speeds) and those that reduce exposure (including separation/segregation of travel modes). However, interventions that reduce the likelihood of a crash alone are less likely to have higher BCRs in LMICs mainly due to compliance issues. A systematic review by Staton et al (2016)[35] reports that harder legislation for speed control yielded no significant crash reductions in developing countries while the insertion of rumble strips and speed bumps decreased fatalities by 55% to 68 %. Simply setting lower speed limits is not be an effective intervention without measures to ensure the limits are followed. While enforcement of speed limits by traffic police may not be affordable for most developing countries[36], speed reduction measures such as speed bumps, rumble strips, roads that segregate high and low-speed users, designing roads to be compatible with the intended function and technological solutions such as speed governors may be better alternatives.

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ANNEX 2: DRIVER TRAINING

This Annex presents a very brief outline of evidence, because this is an important side issue to address in of the current paper, but not the focus of the paper.

Comprehensive methodologically rigorous reviews of multiple evaluation studies as well as recent studies tell a consistent story:

- 2008: School based training: "The results … provide no evidence that driver education reduces road crash involvement, and suggest that it may lead to a modest but potentially important increase in the proportion of teenagers involved in traffic crashes."[37]
- 2009: Post-license driver training: "While no cost-benefit analyses of basic automobile driver training is available, results do not indicate that formal training of drivers and special driver trainings reduces the number of accidents. Thus, the benefits in terms of prevented accidents have not been found to be larger than the costs of these measures."[38]
- 2016: Post license motorcycle rider training: "There was no evidence that this on-road motorcycle rider coaching program reduced the risk of crash."[39]
- 2020: School based training: The consistent findings from these studies have been that high school driver education does not reduce crashes. Furthermore, the trained students get their licenses sooner, and because teenagers have very high crash risks, the net result of high school driver education is increased numbers of crashes.[40]

Finally, note that the above outline of evidence is for car drivers and motorcycle riders. Training may have different effects for drivers of specialized vehicles. Insufficient evidence exists on this subject.

EXPLAINING THE FAILURES IN DRIVER TRAINING

There are several psychological factors behind these consistent and surprising failures of driver training. It is vital to appreciate that when it comes to road user behavior, the critical issue for road safety is not skill or knowledge, but motivation. The primary behaviors contributing to serious crashes are speeding, not wearing a seatbelt, not wearing a helmet, and impaired driving especially drink-driving. None of these are skill issues: driving under the speed limit rather than above it is a motivation issue not a skill, as are wearing a seatbelt or helmet, and choosing not to drive after drinking.[41] Training is well recognized to work in many areas of human behavior, so it seems counter-intuitive that it is ineffective in road safety for car drivers and motorcycle riders. A minimum of training/knowledge is needed for safety: red lights mean stop, where the brakes are on the car, etc. However, it is rare to find a driver who does not have these basics, and so evaluations of driver training are about going beyond these basics and determining whether more skill and more knowledge helps. Not only is more skill only marginally relevant to many key causes

[37] Roberts IG, Kwan I. (2008). School-based driver education for the prevention of traffic crashes. *Cochrane Database of Systematic Reviews* 2001, Issue 3. Art. No.: CD003201. DOI: 10.1002/14651858.CD003201.
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of crashes and deaths, but also more skill leads to more driver over-confidence, more risk taking, and so more crashes. There is independent evidence supporting these causal steps: driver skills training is shown to increase confidence[42] (making existing general over-confidence[43] worse) and increased confidence is associated with increased risk taking.[44] In addition, a classic study showed that on public roads the most skilled drivers (licensed race car and rally drivers) have much higher crash rates than normal drivers.[45]

A POSSIBLE DRIVER TRAINING SUCCESS

As an important exception, there is evidence that supervised on-road driver experience for novice drivers reduces subsequent crash rate.[46] However, even reviews which suggest some benefits note that benefit cost ratios are not known.[47]

One account of this important exceptional positive finding is that practice with a supervising driver creates safe habits in the actual road environment, through reminders of basic behaviors such as wearing a seatbelt and sticking to the speed limit.

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